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A Photo-Voltaic System Voltage Controller with Battery Storage for Independent Uses

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***Abstract**: The research develops a brand-new voltage regulator system for stand-alone photovoltaic installations incorporating battery storage elements. The PV array output experiences fluctuations based on weather factors which result in uncontrolled DC power. The DC-DC converter tracks the maximum power output based on temperature measurements along with the received irradiance levels. The maximum power point tracking (MPPT) requires the perturbation and observes algorithm for its operation. The algorithm provided outstanding performance despite conditions which affected parameters. The system receives its steady state energy from the solar cell array but maintains its dynamic energy through the battery. The control strategy maintains the system efficiency by directing SEPIC converter and bi-direction DCDC converter operation through pre-programmed modes based on the state of the battery and solar cell power supply. There exists an inverter that changes DC-DC converter outputs into AC voltage. The frequency together with the voltage regulation allows control of the AC output. The inverter voltage control uses unipolar sine wave pulse width modulation (SPWM) in a closed loop fashion. The controlled AC voltage is delivered to both grid integration systems and AC independent loads. The entire system development occurs through design and validation using MATLABSIMULINK. AC standalone load simulations demonstrate that the MPPT algorithm along with control strategy and voltage controller using SPWM approach operate effectively for the inverter.*

***Keywords**: Perturbation and Observation, MPPT, Inverter, Bidirectional DC-DC Converter, SEPIC, and Photovoltaic Systems*

I. Introduction

Solar energy now rises as an appealing alternative energy approach thanks to its numerous advantages including extensive availability and pollution-free operation while being a renewable resource. Solar photovoltaic (PV) power demonstrates substantial potential for solving the energy scarcity and environmental contamination issues. For a particular environment the photovoltaic cell has a specific maximum power point (MPP) which transforms over time as illumination from the sun along with ambient temperature change due to the non-linear current-voltage behavior of the photovoltaic cell.

Maximum power point tracking (MPPT) receives various implementations each year including the perturb-and-observe (P&O or hill-climbing) method and the incremental conductance (INC) method and the constant voltage tracking (CVT). The Perturbation and Observation (P&O) method maintains a basic feedback structure because it needs less measurable parameters. The method works through periodic changes of array terminal voltage either upward or downward before checking PV output power against previous perturbation measurements. The peak power tracker uses this method to determine the peak power state during its constant search.

The MPP monitoring system uses DC-DC converters as its main component. The single ended primary inductor converter topology gained noticeable interest among researchers since it can produce both elevated and reduced output voltages than the input voltage. The output of this topology operates without experiencing flipping like fly back or Cuk configurations. The converter features a coupling capacitor that separates input and output voltage levels while operating at PWM control with fixed frequency. Static power converters identified as inverters transform dc power supply into ac output waveforms. The inverter acquires its power supply from SEPIC to generate ac output power. The linkage between the Sepic Converter and Inverter works through a Bi-Directional DC-DC Converter. The control system must regulate both frequency and magnitude of generated sinusoidal ac outputs. Control of inverter output frequency and magnitude occurs through the comparison between a carrier frequency triangular wave to an inverter output wave of equal frequency. SPWM is widely preferred for its straightforward application and ease of

operation since it serves as sinusoidal pulse width modulation. The output voltage magnitude gets regulated by a PI controller-based closed loop control system [10]. A micro-PV system outputting near 160 watts features two PV modules linked in series as its fundamental design component.

A personalized MPPT algorithm solves the micro-PV system structure problems in this research work. The technique uses improved PV array investigation to track the global MPP under all forms of insulation conditions. The battery charging and discharging operations require the use of Bidirectional converters. The Bidirectional Converter operates through Buck mode and Boost mode and Bidirectional mode. The algorithm demonstrated its fast ability to track real MPP during temperature changes through MATLAB-SIMULINK tests. The simulated results using MATLAB prove the operation of the proposed closed-loop system under disturbances from sources and loads.

II. System Configuration

The schematic representation of the proposed solar energy conversion method can be found in Fig. 1. The system consists of a solar cell array and a battery that connects with a single-phase inverter as well as a bi-directional DC-DC converter (BDC) and a SEPIC converter. The solar cell array joins the battery to the DC Bus through dual converters consisting of the Sepic converter followed by the bi-directional DC-DC converter. The battery control regulatory aspects exist in only one device called BDC while maintaining simple system hardware composition. The battery works as an over-load power source (3) and also provides power to the load (2). Controlling the UDC together with BDC enables energy management with guaranteed system efficiency.

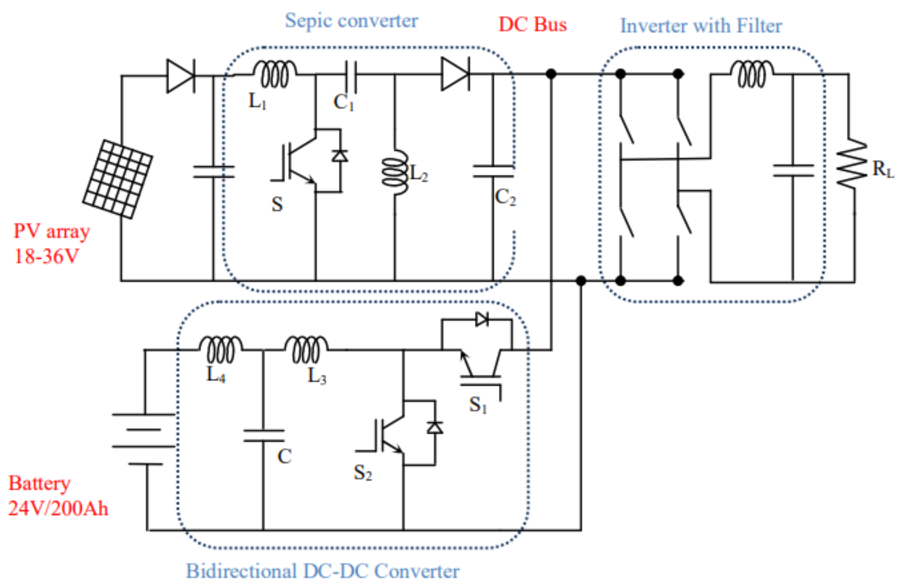

Fig 1: Proposed System configuration

Output power of the SEPIC converter depends on temperature measurements along with radiation readings. To extract the highest possible power from the PV array along with transmission to the stand-alone demand a single-phase inverter operates. Control signals produced by the controller drive the SEPIC converter along with BDC and inverter to extract peak power effectively while handling energy storage and regulating ac voltage frequency at load terminals.

III. SEPIC Converter

The SEPIC buck-boost operation widens the range of usable PV voltage thus enhancing the choice of available PV modules for use. The noninverting polarity together with easy-switch operation and reliable low input-current pulsing enables SEPIC to accomplish high-precision MPPT and this makes SEPIC superior over other converters for the low-power PV charger system. The SEPIC Converter creates a separated connection between input and output terminals following the charging cycle through an isolation channel and suitable voltage elevation. The

two main weaknesses of this circuit include reduced efficiency and necessary use of two inductors. The design of chargers does not focus on efficiency first since the coupling inductor resolves the second main drawback.

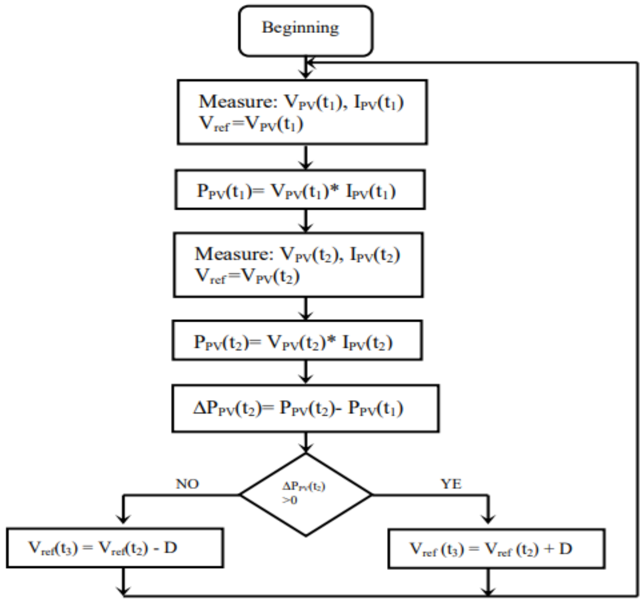

Fig 2: P&O algorithm

IV. Bi-Directional DC-DC Converter

A bidirectional DC-DC converter stands as an essential power electronics subject because it enables power movement between different DC sources. Power travels in the single-direction for buck operation and the reverse-direction activates boost operation. BDC functions in the buck mode and the battery operates in charging mode during periods of excess energy from the PV array. The converter functions in boost mode during overcast or nighttime situations where the battery serves as the power source for the load.

The system achieves this operation through duty cycle management. The LCL circuit provides effective reduction of battery current variations. The Boost-DC-Buck power converter functions in three operational states including bidirectional mode and boost and buck operations. The block diagram of single-phase inverter closed-loop functionality appears in Figure 3. The output voltage of the inverter receives its control from a PI controller. SPWM technology manages the four inverter switches for sine wave pulse width modulation.

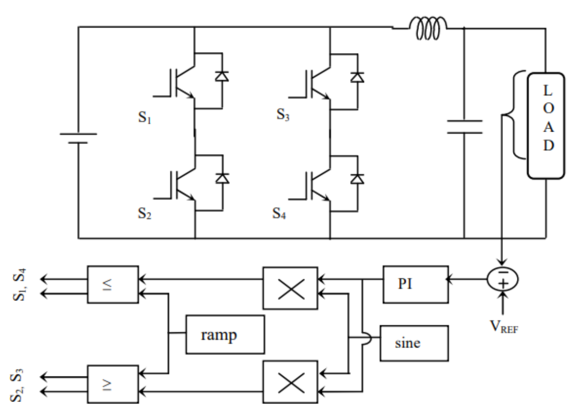

Fig 3: Closed loop operation of PWM inverter

V. Outcomes and Conversations

The simulation results for the proposed scheme appear in figures which show active power provided to the load and load voltage and current along with DC link voltage and current. A series connection of three equivalent solar panels allows voltage to increase by three times while sustaining the same current flow since each panel has Voc = 34.2V and Isc = 6.17A. The adjustments in ambient climate conditions influence both the inverter voltage and current values. The total power output exceeds 180W because these panels operate in serial connection with 60W maximum rating per panel. The main aim involves maximizing the extracted electricity output.

System waveforms of Mode – I

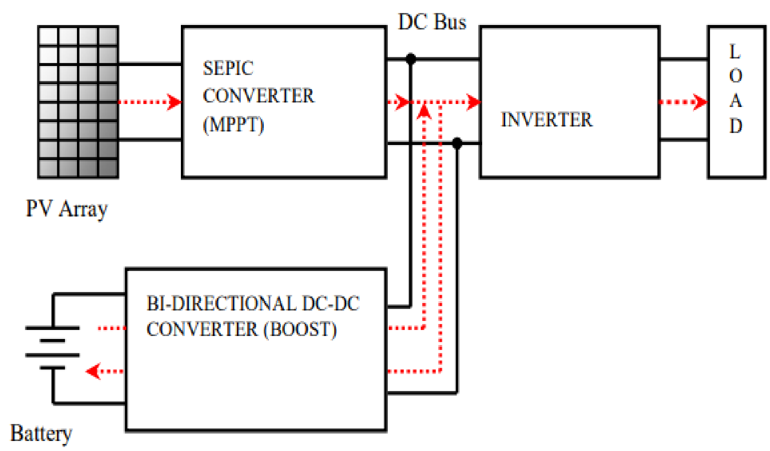

Fig 4: Power management in Mode -1

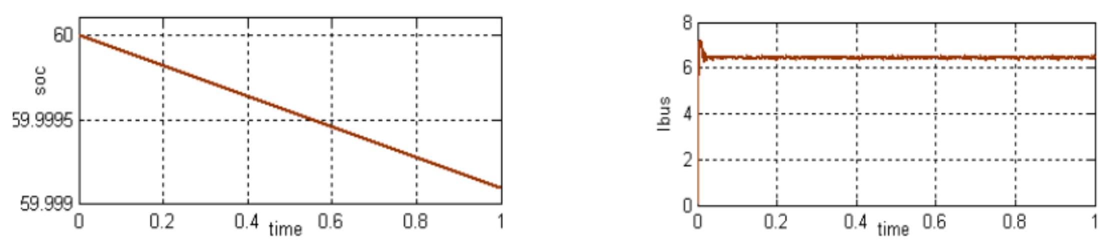

Fig 5: SOC of Battery (Discharging) and Output current of DC bus

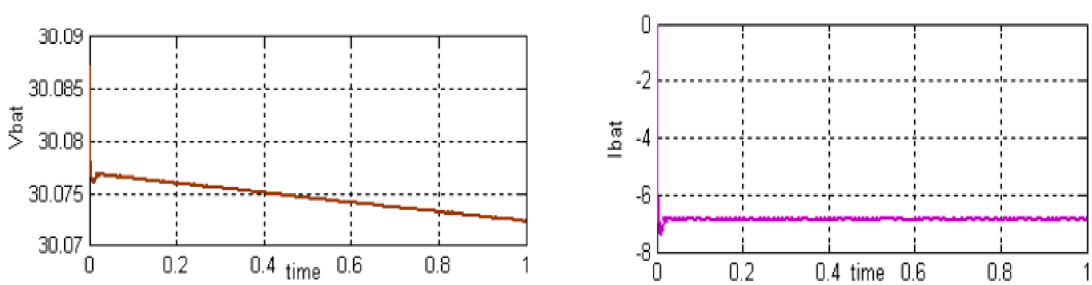

Fig 6: Output Voltage (Vbat) and Output current (Ibat) of Battery

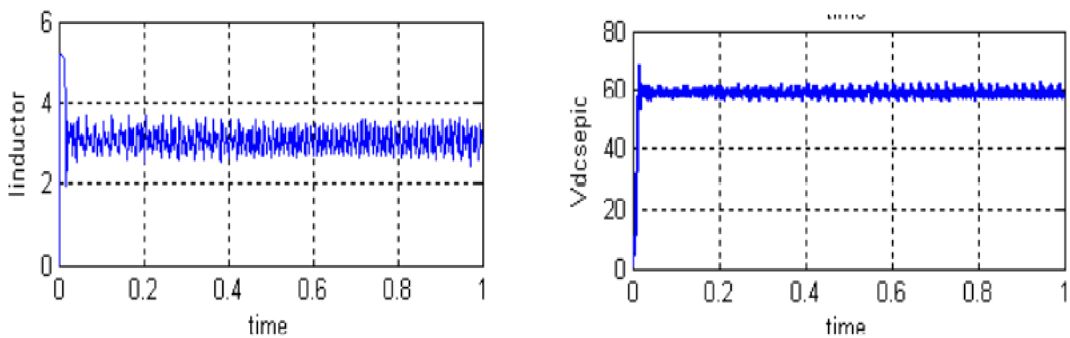

Fig 7: Inductor Current (Il1) and Output Voltage of SEPIC Converter

System waveforms of Mode – II

The BDC transitions to Boost mode into Buck mode to regulate V_{Bat} and I_{Bat} when charging the battery reaches both over-charged-point voltage (32.22V) and maximum charge current in Mode I. Figure 8-9 shows the complete switching patterns corresponding to MODE-II.

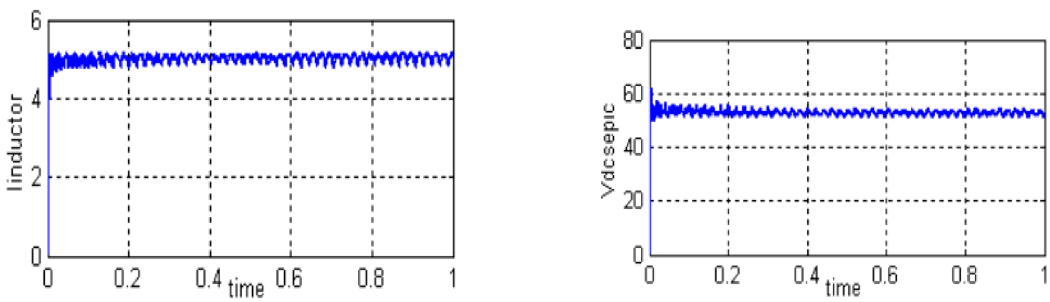

Fig 8: Inductor Current (Il1) and Output Voltage of SEPIC Converter

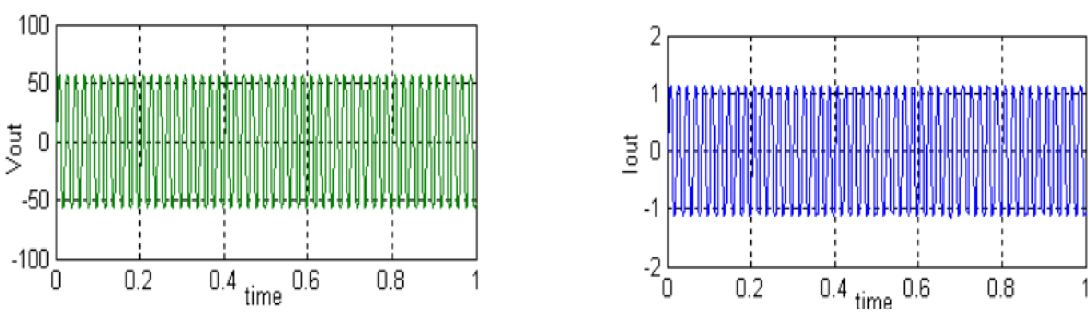

Fig 9: Output Voltage and Output Current of 1-ø Inverter

Output waveforms of change in Buck to Boost Mode

Figure 10 together with Figure 11 show the waveforms during the change from MODE-II to MODE-I operation which represents Buck to Boost mode transition. Regarding MODE-III.

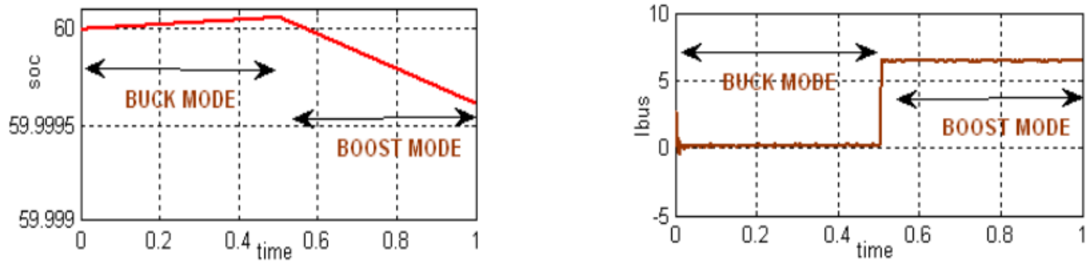

Fig 10: Change in SOC and Bus current (Ibus) from Buck to Boost Mode

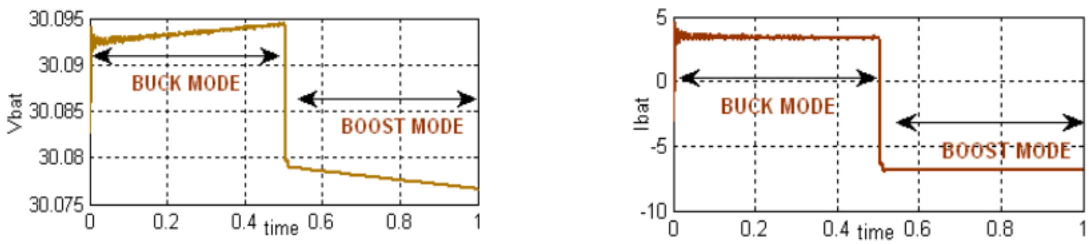

Fig 11: Change in Battery voltage (Vbat) and Ibat from Buck to Boost Mode

Inverter Output Waveforms for Load Disturbance

The inverter's output voltage and current waveforms appear in Figure 12-13 while the reference voltage undergoes different variations.

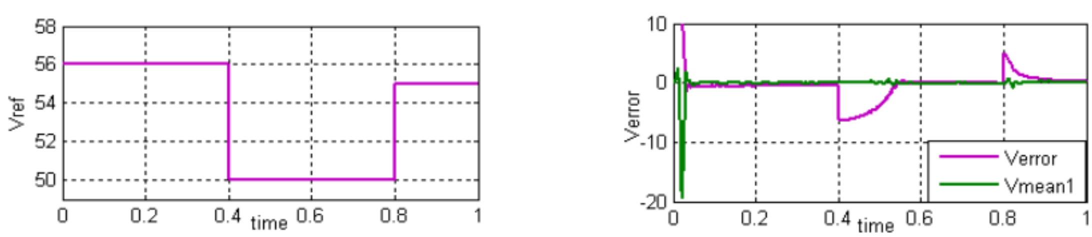

Fig 12: Required output voltage and Error voltage (Vref - Vout)

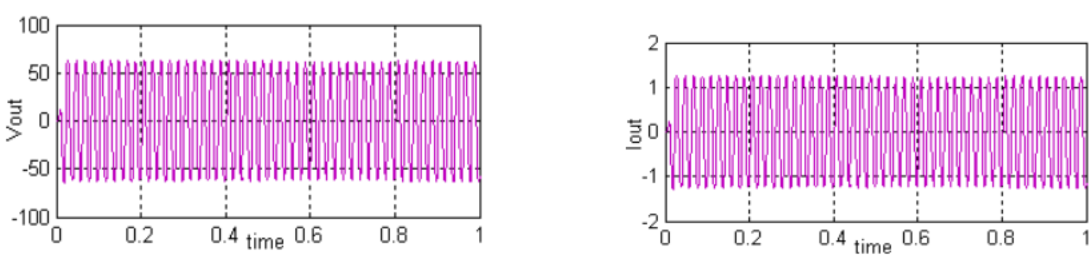

Fig 13: Output Voltage and Output Current of 1-ø Inverter

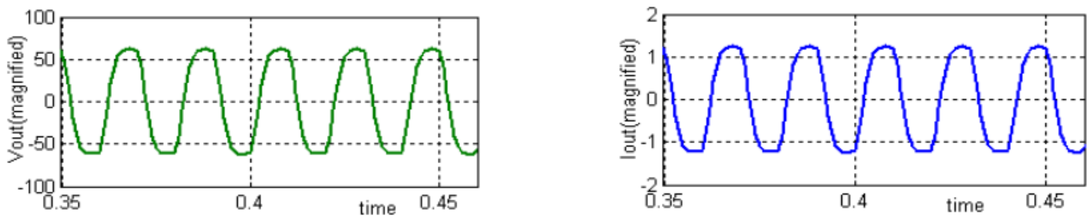

Fig 14: Magnified Output Voltage and Output Current of 1-ø Inverter

Inverter output waveforms for source disturbance

The changing irradiation levels produce output voltage and current waveforms on the inverter according to Figure 14-16.

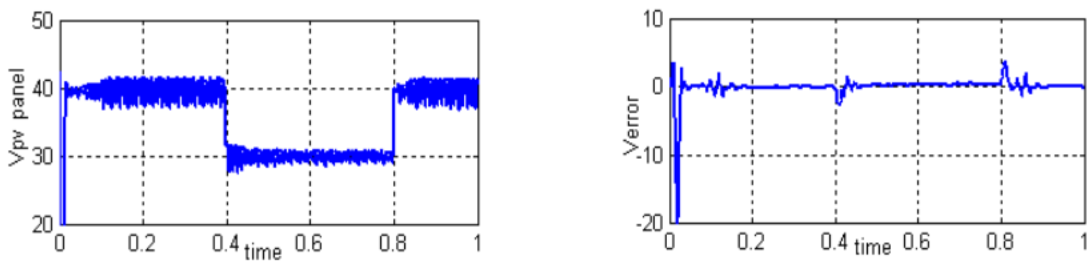

Fig 15: Vpv due to change in irradiation levels and Error voltage (Vref - Vout)

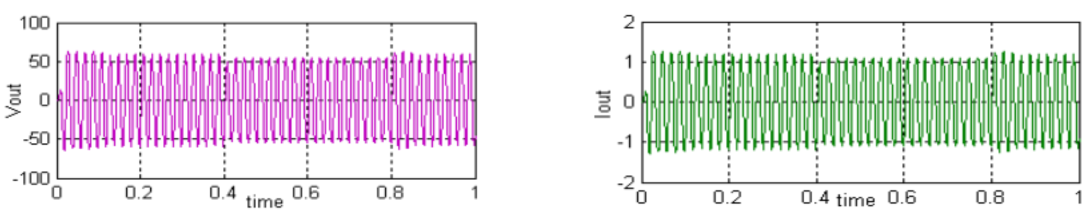

Fig 16: Output Voltage and Output Current of 1-ø Inverter

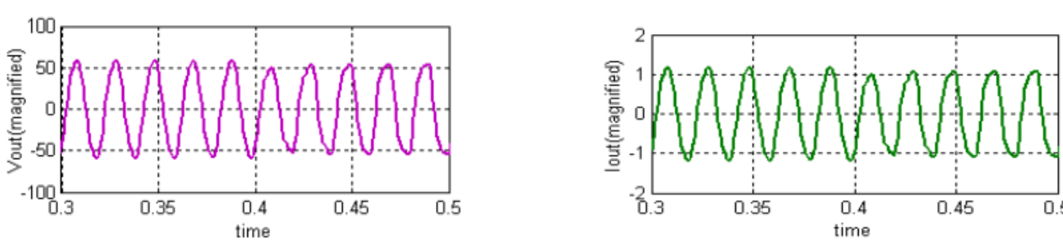

Fig 17: Magnified Output Voltage and Output Current of 1-ø Inverter

VI. Conclusion

The maximum power point tracker needs implementation through MATLAB/SIMULINK software to determine PV array power through simulations of PV-to-stand-alone-load power supply scenarios. The SEPIC-Converter functions in continuous conduction mode to execute the MPPT. The specified control algorithm for the MPPT operates with a perturbation and observe algorithm. Simulation results show that P&O MPPT algorithm

functions to enhance both dynamic and steady state conditions of PV systems. The operating modes of BDC must align with conditions from PV panels and battery storage systems.

The BDC operates through buck and boost functions and shutdown mode which are verified through simulation evaluation. Simulation outcome demonstrates that the photovoltaic system adjusts rapidly under varying irradiance while the inverter output exhibits improved voltage control through SPWM control method operation. The single-phase voltage source PWM inverter benefits from PV generating system-based P&O MPPT technique and BDC and SPWM control making it practical and efficient.

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